1 **Waterway Performance Monitoring via Automatic Identification System (AIS) Data**
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ABSTRACT

Fiscal constraints at the federal level are driving the need for more robust and objective performance evaluation methodologies for use by the U.S. Army Corps of Engineers (USACE) as it carries out its civil works mission in support of the nation's water resources infrastructure. One specific area of need concerns functional performance evaluation of dredged navigation channels at the local level as well as performance evaluation of the systems of navigation projects. The Nationwide Automatic Identification System (NAIS) for vessels operating in coastal waters, instituted within the United States following the terrorist attacks of September 2001 and maintained by the U.S. Coast Guard, represents an enabling technology for providing the data required for quantitative performance assessments of Corps-maintained navigation infrastructure. In this paper, several applications of archival AIS data towards waterway performance evaluation are presented. An assessment and comparison of several deep-draft coastal ports concerning the sensitivity of the timing of vessel transits with tidal elevations is presented. The AIS data archive is also applied towards a point-to-point transit time monitoring strategy at the local and regional levels. As the Corps confronts an uncertain fiscal outlook and constrained budgets for annual operations and maintenance activities, these metrics as well as other potential applications of archival AIS data can play a valuable role in providing objective, quantitative assessments of waterway performance.

INTRODUCTION

The United States Coast Guard (USCG) maintains the Nationwide Automatic Identification System (NAIS: http://www.uscg.mil/acquisition/nais/) to collect real-time traffic monitoring data on vessels operating in U.S. territorial waters. Transceivers onboard the vessels broadcast the AIS signal containing position, heading, speed, and other identifying information to shore-based towers with a reporting interval of only a few seconds for vessels underway. Technical characteristics of the AIS technology are specified by the International Telecommunication Union, which describes ship-to-ship communication and improved navigation safety as the primary uses for AIS (ITU, 2010). Therefore, the system is intended primarily for collision-avoidance and general maritime domain awareness (MDO) to improve safety and security, support search and rescue efforts, and enhance environmental stewardship. As the lead federal agency overseeing national implementation of AIS, the USCG has identified technical and user limitations inherent within AIS technology, and has sought to improve data quality and availability (Winkler, 2012). The USCG maintains a network of shore-based towers for receiving the AIS reports from vessels operating in coastal waters and also for broadcasting MDO-related messages to the vessel.

The U.S. Army Corps of Engineers (USACE), through development of its Lock Operations Management Application (LOMA: http://loma.usace.army.mil/), maintains a complimentary system of AIS towers on many of its locks and dams along navigable inland rivers and waterways. The USACE and the USCG have a data-sharing agreement in place to exchange AIS position reports received via the respective networks of receiving towers. In addition to the live picture of waterway traffic conditions provided by the AIS technology, vessel reports are archived for several years from time of receipt, resulting in an enormous volume of data concerning vessel utilization patterns and trends in coastal and inland waterways. The work presented in this paper represents some initial applications of the archival AIS data towards performance evaluation of USACE-maintained coastal navigation projects and inland waterways.

Concerning confidentiality issues with AIS data, it should be noted that there are no legal restrictions on the general collection and use of AIS data. Anyone may procure the hardware and software required to receive and process the AIS position reports from vessels, and in fact there are numerous commercial providers of AIS data and accompanying software analysis packages available. The work presented in this paper represents some initial applications of the archival AIS data towards performance evaluation of USACE-maintained coastal navigation projects and inland waterways.

BACKGROUND

Use of archival AIS records as the equivalent of a remote sensing technology for inferring aspects of navigation system behavior and performance has been growing as the technology has become more prevalent. Application of archival AIS data at the local and port levels appear

most commonly in the literature. Schwehr and McGillivary (2007) investigate AIS for tracking illegal oil discharges from vessels as well as real-time monitoring of traffic patterns to improve incident response times and management actions. Hatch et al. (2008) use AIS data to identify the contributions of large oceangoing vessels to noise levels near shipping lanes in a National Marine Sanctuary off the coast of Massachusetts, raising concerns about the effects of ship noise on endangered whales. Dobbins et al. (2013) use AIS data from the vicinity of Paducah, KY along the lower Ohio River as a proof of concept for vessel trip generation to improve upon existing data sources (e.g. the USACE Waterborne Commerce Statistics and the Lock Performance Management System). Cluster analysis on the data shows that it is possible to identify obstruction and fleeting areas, such as locks and dams. Origin-Destination (OD) pairing, a process adopted for the work shown in this paper, makes it possible to generate trip counts for 41 possible movements, and results are reported above 25 trips per pair. Shu et al. (2013) use ShowRoute software developed by the Marine Research Institute, the Netherlands (MARIN) to investigate forcing factors that affect ship path and speed. For the port area considered, it was found that sight distance and wind had statistically significant affects on both path and speed of transiting vessels.

Examples of AIS data being applied at larger regional scales and over longer time horizons include the Marine Cadastre project, a joint effort between the National Oceanographic and Atmospheric Administration (NOAA) and the Bureau of Ocean Energy Management (BOEM), which has used AIS data in support of marine spatial planning (NOAA/BOEM, 2012). Additionally, aggregated AIS data has been used recently by the USCG for the Atlantic Coast Port Access Route Study (USCG, 2012), providing a detailed map of shipping lanes along the Atlantic coast. Other studies have investigated use of AIS to inform risk management strategies across a variety of spatial and temporal domains. Calder and Schwehr (2009) explore the use of AIS data for calibrating risk assessment methods with regard to charting uncertainty, and for detailing maritime traffic composition. AIS data is discussed in a maritime domain risk-assessment context in Dobbins and Abkowitz (2002) and in Dobbins and Jenkins (2011).

In this paper, archival AIS data is applied towards both a tidal influence assessment for vessels calling at deep-draft coastal ports as well as a waterway transit time analysis over a range of spatial and temporal domains.

TIDAL INFLUENCE ANALYSIS
The concept of tidal delays routinely surfaces in the discussion of funding for maintenance and design of navigation projects. Tidal delays are caused when vessels are restricted in operation due to the elevation of the water surface due to tidal influence. Restrictions generally come in the form of insufficient underkeel clearance or insufficient air draft clearance while in transit. Adverse currents may also be present due to the ebb and flow of the tide. Tidal delays are of interest because they represent unproductive operating costs for commercial vessels. Anecdotally, it is well-known that commercial vessels frequently time their arrivals to and

1   departures from coastal ports with high tide water levels to take advantage of the additional
2   underkeel clearance and thereby load to drafts that would otherwise be restricted. However,
3   heretofore there has been no consistent or objective approach for quantifying this tidal influence
4   on the timing of vessel transits. This information is of interest to the USACE because
5   quantitative knowledge of tidal influences on vessel behavior at deep-draft navigation projects
6   could have significant implications for how limited maintenance dredging resources are allocated
7   each year.

8   An overarching problem in the quantification of tidal delay factors is the variety of tidal
9   scenarios. Tides are described as diurnal, semi-diurnal, or mixed. Tidal ranges vary
10   significantly, from as little as 1 foot to over 30 feet, depending on location and topography.
11   Presence or absence of a particular tide range or form doesn't indicate the presence of tidal
12   delay. Generally, the behavior of vessels in operation is the only reliable indicator of tidal delay.
13   However, most vessel operation data is developed indirectly from shipping reports or pilot data.
14   AIS enables the ability to investigate vessel performance directly.

15   The general hypothesis of this investigation is that vessels, when unconstrained by underkeel
16   clearance or air draft, will operate independent of tidal forcings. In other words, vessels will act
17   as random probes of the water surface elevation measured at a fixed point. Over time, the
18   frequency distribution of water surface elevation resulting from tidal forcing, and the frequency
19   distribution of water levels observed by ships in transit will converge, as the respective statistical
20   populations of observations grow large. This hypothesis was tested using archival AIS data at
21   the following US coastal ports: Boston, MA, Matagorda Bay, TX, Port Hueneme, CA, Columbia
22   River Entrance, OR, and Anchorage, AK. In each location a reference area was used to isolate a
23   sample of archival AIS data. NOAA 6-minute tidal predictions were obtained for 2011 at tide
24   gauges close to the reference areas, and the reference areas were selected in part due to their
25   proximity to NOAA tide stations. Predicted elevations were chosen because it was believed
26   these would be used by ship schedulers to plan voyages.

27   For each location, 87,600 tidal predictions (1-year of 6-minute data) were used to develop
28   threshold values for high, mid, and low tide designations for 2011. High tide was defined as the
29   upper quartile of predictions, Low tide was defined as the lower quartile, and Mid tide was
30   defined as elevations within the two inner-quartiles. The water level threshold values delineating
31   these tidal regions, shown in Table 1, are used to describe the observed traffic as occurring at
32   high, mid, or low tide for the 2011 reference period at each port. To accomplish this, for each
33   reference area, the water elevation at the time of each vessel transit are recorded. A static line
34   perpendicular to the channel center line is used as a reference, and the time of vessel crossing is
35   linearly interpolated based on the time stamps of the two vessel position reports closest to the
36   line on either side. This recorded time is used to interpolate a corresponding tidal elevation from
37   the record of tidal predictions, which is then assigned to the particular vessel transit. For each
38   reference area, the transit elevations are ordered highest-to-lowest and the cumulative
39   distribution function (CDF) calculated. The CDF curve for transit elevations is then evaluated at

1 the Low and High tide thresholds set previously to obtain the percentage of vessels transiting
2 within each range.

3

4 TABLE 1 Tide Stations Analyzed and Percentages of vessels transiting at Low, Mid, and High
5 Tide

Port Area (NOAA Tide Gage)	High Low Thresholds (Ft, MLLW)	% Traffic at Low Tide			% Traffic at Mid Tide			% Traffic at High Tide		
		All	In-bound	Out-bound	All	In-bound	Out-bound	All	In-bound	Out-bound
Boston, MA (8443970)	8.34 2.05	21.2	18.9	23.3	52.8	52.8	52.7	26.0	28.3	24.0
Matagorda Bay, TX (8773701)	0.74 0.10	24.7	25.8	23.7	52.0	50.8	52.9	23.3	23.3	23.4
Port Hueneme, CA (9411340)	3.88 1.72	24.6	22.0	27.1	50.8	55.9	45.8	24.6	22.0	27.1
Columbia River, OR (9439040)	6.67 2.52	26.8	28.3	25.3	49.3	49.1	49.5	23.9	22.6	25.3
Anchorage, AK (8443970)	24.43 8.75	9.9	6.6	13.2	57.9	68.9	46.8	32.2	24.6	39.9

6
7 With the exception of the extreme tidal range at Anchorage, AK and subsequent strong
8 preferences for Mid and High tidal elevations shown by transiting vessels, the percentages shown
9 in Table 1 for Low, Mid, and High tide ranges do not deviate more than single-digit percentages
10 from the baseline values of 25%, 50%, and 25%, respectively. Nonetheless, there are some
11 notable shifts in the percentages, particularly when comparing inbound to outbound vessels, that
12 appear to confirm the influence of tidal elevations on when vessel operators time the transits of
13 the entrance channels considered. For example, at Boston, MA, over 28% of inbound vessels
14 transit in the high tide range while less than 19% of inbound vessels transit in the low tide range,
15 indicating a clear preference for high (and to a lesser extent, mid) tide range.

16

17 The distribution of traffic across the tidal prism is next assessed using a modification to the
18 approach proposed by Scully and Mitchell (2013). A single tidal dependence parameter, TD, is
19 defined as shown in Eq. 1:

20 $\qquad TD = (T_{75} - T_{25}) / T_{50}$ $\qquad\qquad\qquad$ (1)

1

2 Where T_{75} is the percentage of vessels transiting during the upper 25% of water levels, T_{25} is the
3 percentage of vessels transiting during the lower 25% of water levels, and T_{50} is the percentage
4 of vessels transiting during the middle 50% of water levels. Given this arrangement, TD values
5 will be positive when vessels show a preference for the upper 25% of water levels, and negative
6 when the preference is for the lower 25%. For situations where T_{50} is less than 50%, the
7 decreasing value of the denominator term will serve to increase the absolute value of TD, thereby
8 helping to convey the extent to which vessels depend on high or low water levels. The TD
9 descriptions for each port considered in this study are shown in Table 2.

10

11 Table 2 TD and TP parameters for all, inbound, and outbound vessel populations

Parameter	Boston, MA	Matagorda, TX	Port Hueneme, CA	Columbia River, OR	Anchorage, AK
TD, All	0.091	-0.027	0.000	-0.059	0.385
TD, Inbound	0.178	-0.049	0.000	-0.116	0.261
TD, Outbound	0.013	-0.006	0.000	0.000	0.571

12
13 One shortcoming of the TD parameter as defined in Eq. 1 is shown by the results for Port
14 Hueneme, CA. Because T_{75} and T_{25} are equal for all three scenarios analyzed, TD is equal to
15 zero and the large inbound/outbound split for T_{50} (shown by different percentages in Table 1) is
16 not conveyed.

17 The percentages shown in Table 1 as well as the TD values shown in Table 2 are useful for
18 quickly ascertaining the magnitude of tidal influence on the timing of vessel transits through
19 coastal entrance channels. However, one issue that needs to be addressed concerns to degree to
20 which sampling error may be present, thereby producing TD values that deviate from 0.0 when
21 in fact no statistically significant tidal influence is present. To address this, difference of means
22 hypothesis testing is used at each location to test the following hypotheses at the 95% confidence
23 level:

24 1. The mean of the full population of 6-min tidal elevations is equal to the mean of the
25 population of water levels observed during all vessel transits.

26 2. The mean of the full population of 6-min tidal elevations is equal to the mean of the
27 population of water levels observed during all inbound vessel transits.

28 3. The mean of the full population of 6-min tidal elevations is equal to the mean of the
29 population of water levels observed during all outbound vessels transits.

30 The results of the hypothesis tests are shown in Table 3. Rejecting the hypothesis means that,
31 with 95% confidence, the sample means between the respective populations of water levels are
32 significantly different. That is, there is a statistically significant tidal influence on the timing of
33 vessel transits present at that location.

1

Table 3 Hypothesis test results for difference of means for all, inbound, and outbound vessel
transit elevations versus that of 6-min water levels

Hypothesis	Boston, MA	Matagorda, TX	Port Hueneme, CA	Columbia River, OR	Anchorage, AK
1 (all vessels)	Reject	Reject	Fail to Reject	Reject	Reject
2 (inbound)	Reject	Reject	Fail to Reject	Reject	Reject
3 (outbound)	Fail to Reject	Reject	Fail to Reject	Fail to Reject	Reject

4
5   Of the five ports considered, only Port Hueneme, CA does not show a statistically significant
6   difference from the mean water elevation for all three populations of transit elevations
7   considered. Interestingly, the only locations to show a statistically significant difference in
8   means for all three populations, Anchorage, AK and Matagorda Bay, TX, also happen to be the
9   locations with the highest and lowest tidal ranges considered, respectively. This is somewhat
10   surprising in the case of Matagorda Bay, and could indicate that tidally induced currents, as
11   opposed to water elevations, play a key role in the timing of vessel transits.

12

13   **WATERWAY TRAVEL TIME ANALYSIS**
14   Another potential application of the AIS archival data that has tremendous implications for the
15   manner in which navigable waterways are managed, monitored, and maintained is to extract
16   travel time statistics for the population of vessels using various portions of the marine
17   transportation system (MTS). This approach is straightforward in individual channels and
18   localized port areas where vessels underway are not likely to deviate much from a set course
19   through the zone in question (e.g. transiting a coastal entrance channel). For single vessels or
20   small samples of data, one need only compare the time stamps on the first and last reports from
21   unique vessels within the area of interest to determine transit time, or estimate transit time using
22   one or more speed over ground reports and the distance being traversed. However, for larger
23   and/or more complex port zones, where vessels have a number of possible routes to take to
24   various destinations or where anchorages, moorings, detours, or other deviations from a set
25   course are likely to occur, extraction of travel times becomes more involved and additional
26   considerations must be made.

27   In this section, AIS archival data is examined at a range of spatial and temporal scales for
28   determining travel time statistics through various portions of the MTS.   A 1-year sample of data
29   from Charleston Harbor, SC is used to extract travel times between the entrance channel and
30   container terminals on the Wando and Cooper Rivers, respectively. In addition, vessels traveling
31   throughout the inland river system are tracked over a 6-week period, and their position reports
32   used to generate travel times statistics for portions of the Mississippi Rivers. In both the
33   Charleston Harbor and inland river exercises, geospatial filtering is applied to the AIS position
34   reports to indicate when a particular vessel has traveled from one area of interest to another.

1   Finally, an alternative approach for extracting travel times is investigated using the voyage
2   Destination field embedded within the AIS message and entered by the vessel operators. The
3   voyage histories of eleven vessels operating on the Great Lakes system are accessed over a
4   multi-year history, and the Destination fields are used in an attempt to reconstruct past trip
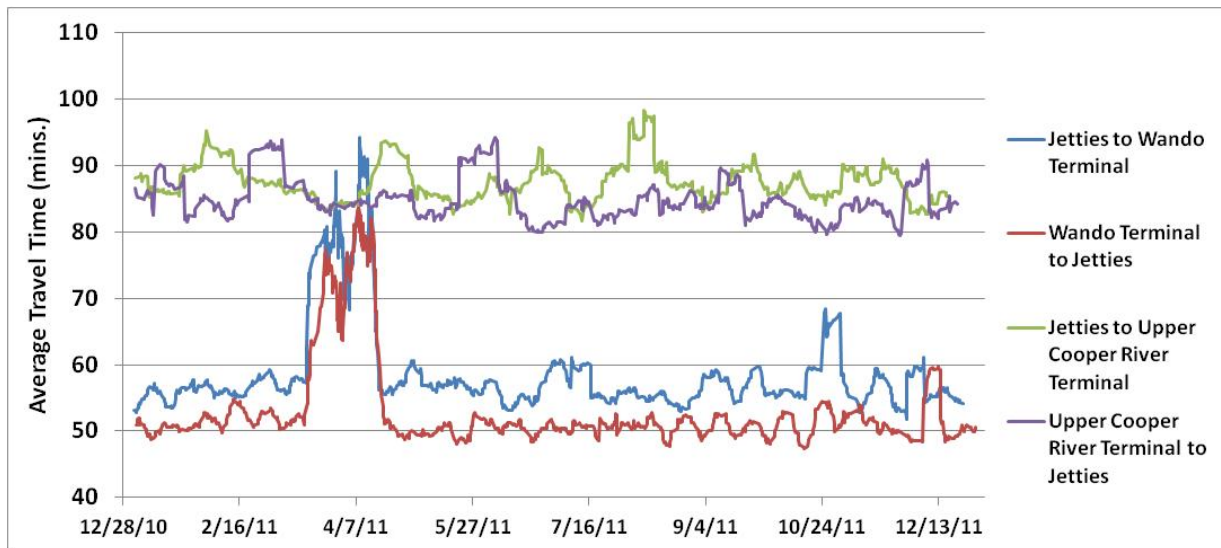5   itineraries.

6

7   *Charleston Harbor, South Carolina*
8   All AIS vessel reports for Charleston Harbor from 2011 were analyzed in order to extract travel
9   time statistics and trends between the Entrance Channel near the jetties to the container terminals
10   on the Wando River and Cooper River (just above the I-526 bridge), respectively. The 1-year
11   record consisted of over 8.1M individual vessel reports, and this exercise is intended to
12   demonstrate an efficient methodology for extracting travel times between two arbitrary, but non-
13   overlapping areas of interest (AOIs). Bounding coordinates for each of the three AOIs
14   considered here are used to filter the reports, leaving a much smaller data set for extracting travel
15   times between locations. Within this smaller data set, the time difference between when a single
16   vessel leaves one AOI and when it enters another AOI is taken to be the travel time.

17   More formally, this process, the same employed by Dobbins and Langsdon (2013) for extracting
18   trips from the population of vessel reports and measuring travel times between AOIs, can be
19   described thusly:

20   1. Spatially filter vessel reports based on non-overlapping area of interest (AOI) dimensions

21   2. For each report falling within AOI confines, add field with unique AOI label

22   3. Group all spatially filtered reports (with AOI labels) by vessel unique ID (MMSI, IMO,
23   or Vessel Name)

24   4. For each unique vessel, sort reports based on Date-Time field

25   5. Within sorted list, for any two consecutive reports from the same unique vessel but
26   different AOI labels, record difference in Date-Time field

27

28   Using this process the mean travel time for inbound vessels between the Entrance Channel and
29   the Wando terminal is found to be 59.7 minutes, with a standard deviation of 17.7 minutes.
30   Outbound vessels transiting between the same two AOIs show a mean travel time of 54.1
31   minutes, with a standard deviation of 14.6 minutes. The mean travel time for inbound vessels
32   between the Entrance and the Cooper River terminal is 87.5 minutes, with a standard deviation
33   of 12.3 minutes; outbound vessels had a mean travel time of 84.8 minutes, with a standard
34   deviation of 15.0 minutes. Figure 1 shows the 20-point rolling average travel times for inbound
35   and outbound between the AOIs of interest as distributed across all of 2011, and provides a sense
36   of the degree of variation present in the travel time data.

1

2

3   Figure 1 Travel times between the Charleston Entrance and the Wando River and Cooper River
4   container terminals during 2011

5   It is immediately apparent that average travel times between the Jetties and Wando Terminal
6   increase dramatically beginning in mid-March 2011 and running through mid-April.   In this
7   particular case, these transit times can be traced back to three particular harbor tugs making
8   multiple trips per day between the respective AOIs. Many foreign flagged and domestic
9   oceangoing vessels are observed making the same transits and posting travel times in line with
10 prevailing average values. Therefore, in this case, it appears that harbor operations unique to
11 these particular vessels (perhaps dredge tenders), as opposed to conditions in the navigation
12 channels, are behind the increase in observed travel times. Nonetheless, the potential for this
13 approach to highlight changes in aggregate waterway performance (as measured by prevailing
14 travel times) is clearly demonstrated.

15 One item of note concerns outlier transit times which clearly fall outside the range of normal
16 variability. The 5-step process outlined above does not distinguish vessels which travel directly
17 between the two AOIs from vessels that pause, reroute, or dock while transiting between them.
18 Therefore, careful considerations must be made to help ensure that extracted travel times
19 accurately capture normal waterway operating conditions and are not biased upward.

20 ***Inland River example***

21 To demonstrate the scalability, both spatially and temporally, of the 5-step process for extracting
22 transit times described above, a second exercise is conducted over portions of the inland river
23 system. The AIS vessel position reports for all vessels transiting by Cairo, IL are extracted from
24 the USCG archive for a 6-week time period in early 2013. This results in 521 unique vessels,
25 and the full tracks of those vessels over the entire 6-week period are obtained in order to observe
26 travel times throughout the inland river system, not just in the vicinity of Cairo. To reduce the

1 size of the data files needed to support this analysis, the time between vessel reports is increased
2 to several minutes, instead of the usual 6-second reporting interval for vessels underway. The
3 extent of travel throughout the inland system over the 6-week period is impressive in its extent,
4 with locales such as Muskogee, OK, Marseilles, IL, and Houston, TX, among many others, all
5 visited on multiple occasions. The same data filtering process employed in the Charleston
6 Harbor exercise is used here, the primary difference being a much larger number of AOIs. The
7 resulting transit time statistics extracted for portions of the Mississippi River are shown in Table
8 4.

9 TABLE 4 Travel time statistics along portions of the Mississippi River

Inland Port Area AOI	Approx. River Mile Distance	Downbound Travel Time (hrs) Mean Standard Deviation 5th percentile # of observations	Upbound Travel Time (hrs) Mean Standard Deviation 5th percentile # of observations
St. Louis, MO			
	175	27.0 8.5 17.0 211	45.4 12.9 29.3 233
Cairo, IL			
	215	25.2 12.0 17.0 413	55.1 14.3 36.4 371
Memphis, TN			
	285	34.4 12.7 23.2 154	52.1 6.1 39.4 47
Vicksburg, MS			
	125	13.5 4.9 9.5 169	31.5 15.3 19.0 183
Old River, LA			
	75	7.5 2.8 5.1 277	12.7 3.5 8.8 261
Baton Rouge, LA			
	58	6.2 4.6 3.6 242	8.0 2.6 5.2 227
Donaldsonville, LA			

10

1 Figure 2 shows the variation in these average travel times between several AOIs over the
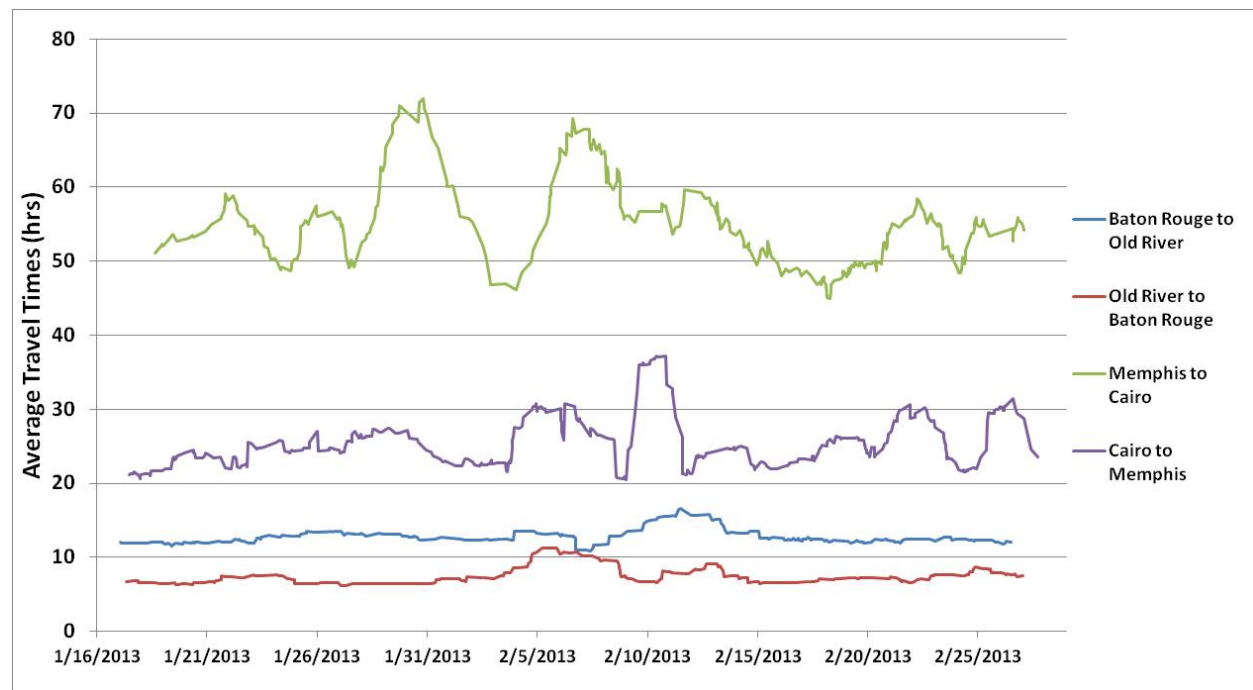2 duration of the 6-week observation period.

4 Figure 2 20-point rolling average observed travel times between Baton Rouge and Old River,
5 and Memphis to Cairo, for upbound and downbound vessels, respectively

6

7 The travel time results in Table 4 and Figure 2 clearly show that downbound vessels on the
8 Mississippi River are able to travel at greater speeds than those of upbound vessels, owing to the
9 downbound currents. Even with averaging over 20 consecutive observed travel times, these
10 inland river travel times can vary widely, owing to the large distances between AOIs and the
11 high likelihood of vessels not transiting directly from one port location to another. Also, river
12 stages, downbound currents, and traffic congestion levels on the river can have significant effects
13 on travel times as well. Therefore, in Table 4 the 5th percentile transit times are also included to
14 help provide a benchmark with which to assess rest of the extracted travel times.

15 In general, more transits are observed between AOIs that are in closer proximity to one another
16 than for those spread far apart. This is due in part to the increased distances between the AOIs,
17 and the resulting higher likelihood that any particular vessel will change course, moor, dock, or
18 otherwise deviate from a typical transit. Another factor to consider is the coverage reliability of
19 the AIS receiving towers collecting the broadcast signals from the vessels. In the data extracted
20 for this exercise, gaps in the coverage records (due to power outages, equipment malfunctioning,
21 and/or software problems) can be seen for many portions of river between Memphis and
22 Vicksburg. This can cause many otherwise valid travel time observations to be missed if a

1   vessel transits an AOI without an AIS position report being received and archived, as shown by

2   the reduced number of observations associated with the Vicksburg AOI.

3

4   ***Great Lakes ports***

5   An alternate approach to that employed so far for extracting travel times between portions of

6   waterway is presented in this section. Rather than extract these times via a process of spatial

7   filtering and sorting of the individual AIS vessel reports, this approach attempts to recreate

8   voyage itineraries via an operator-input Destination field, in which a text string is used to

9   identify the next port of call for a vessel underway. The advantage to this approach is that very

10   large spatial and temporal domains can be covered with much smaller file size and data

11   processing demands. The AIS data archive contains both static and dynamic vessel information.

12   The static data refers to vessel characteristics that do not change over the course of a voyage,

13   such as dimensions and draft. The dynamic data covers all the fields that change as the vessel

14   proceeds on its way, such as location, speed, and heading. Because the Destination field used in

15   this approach is part of the static data set, it does not change (nor should it) over the course of a

16   unique voyage. Therefore, a single data point can capture what might potentially require the

17   processing of thousands or even millions of individual vessel reports to obtain via the method

18   described previously, namely the ultimate destination of any particular vessel underway.

19   For this Great Lakes ports example, the voyage histories of 11 randomly selected vessels are

20   accessed from Oct 2007 through June 2013. For data processing requirements comparison with

21   the other examples presented in this paper, this data extract resulted in fewer than 10 thousand

22   entries, even though the time period covered several years and the number of vessels is larger

23   than in the inland river example. However it should be noted that the quality of data, both in

24   terms of accuracy and completeness, is questionable prior to 2009. For each unique vessel, the

25   static reports are sorted chronologically, and the Destination field entry from one voyage is taken

26   to be the origin of the subsequent voyage. In the case of consecutive voyages with the same

27   Destination field, as well as in the case of extremely long (i.e. months) intervals between the end

28   of one voyage and the start of the next, the entries are removed from the sample to be analyzed.

29   With origin and destination fields established, the respective transit time for any voyage can then

30   be computed based on the Start and End times in the AIS voyage record.

31   Table 6 summarizes some of the notable travel times extracted for the Great Lakes system based

32   on the voyage histories reconstructed with the Destination field from the AIS static reports. In

33   spite of the much lower data processing and file management requirements of this alternate

34   approach to travel time extraction, the voyage history approach presents many challenges owing

35   to data quality problems with the user-input Destination fields. There is wide variation observed

36   on calculated voyage times, with many seemingly erroneous voyage entries lasting only a few

37   minutes. In other cases, it is apparent that the Destination field is not consistently reset or

38   updated between voyages to reflect the changed vessel itinerary. Also, there is no standard

1 labeling convention for the Destination field, and misspelled entries, cryptic abbreviations, and
2 otherwise difficult to decipher and/or locate entries are common.

3

4 TABLE 6 Travel times between Great Lakes ports based on AIS voyage history data

Voyage Origin-Destination AOI	Mean Travel Time (hrs)	Standard Deviation (hrs)	Number of Voyages observed
Duluth-Superior – St. Clair River	67.2	6.3	155
Duluth-Superior – Lower Lake Michigan	76.3	11.0	91
Duluth-Superior – Conneaut, OH	79.7	6.3	13
Cleveland, OH – Alpena, MI	31.5	9.2	27
Silver Bay, MN – Cleveland, OH	68.9	17.5	39

5

6 Nonetheless, the results in Table 6 do show a degree of consistency given the respective
7 distances of each voyage, and there is obviously useful information to be gleaned from this
8 approach provided sufficient data quality assurance is conducted. Over the range of years
9 covered, it is observed that voyages cease during the winter months when the shipping season on
10 the Great Lakes closes, thereby lending a measure of validity to the voyage history data.

11

12 **SUMMARY AND CONCLUSIONS**
13 In this paper, two main applications of archival AIS data towards waterway performance
14 evaluation are presented. The first is a comparison of several deep-draft coastal ports concerning
15 the sensitivity of the timing of vessel transits with tidal elevations at each respective location. A
16 methodology is introduced to objectively quantify and compare the resulting tidal influence at
17 deep-draft coastal entrance channels. This tidal analysis via AIS archival data presents an
18 objective way to quantify the degree to which vessel operations in coastal port areas are
19 influenced by tidal elevations. The TD parameter provides a straightforward and intuitive means
20 of quickly comparing multiple locations, thereby helping to inform regional and national level
21 assessments of the relative impacts of tidal influence on port operations. The difference of
22 means hypothesis testing overcomes the questions created by sampling uncertainty, and will
23 prove most valuable as the methodology is extending to subsets (i.e. smaller populations) of
24 vessels grouped by draft, type, and dimensions. Such information has significant implications
25 for the manner in which the USACE evaluates the criticality of annual maintenance dredging
26 budget requests.

1 In the second application, the AIS data archive is applied towards a point-to-point transit time
2 monitoring strategy, which provides the USACE with baseline waterway performance
3 information needed to monitor the effects of future budgetary and operational decisions on
4 navigation mission execution. Example travel time results are shown for portions of the
5 Mississippi River, as well as for channels within Charleston Harbor, SC. A five-step spatial
6 filtering and data sorting approach is described that is shown to be applicable across a range of
7 spatial and temporal domains. To increase the number of transits observed via this approach and
8 to improve upon the consistency of extracted transit times, it is preferable to create AOIs in
9 relatively close proximity to one another. An alternative approach for extracting travel time data
10 from the AIS reports is also presented for the Great Lakes region, however; data quality concerns
11 limit the applicability of this approach at the present time. The data quality limitations of the
12 voyage history data would appear to offset the advantages of the much smaller initial file sizes
13 and data processing requirements. Further development of a methodology could cause this
14 assessment to be revised.

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